National Aeronautics and Space Administration

# Swept-Wing Ice Accretion Characterization and Aerodynamics

## Research Plans and Current Status

Andy P. Broeren
NASA Glenn Research Center

2011 Annual Technical Meeting
May 10–12, 2011
St. Louis, MO

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# Introduction



**Airframe Icing Technical Challenge**

Goal for Airframe Icing Simulation and Engineering Tool Capability (FY25):

- Achieve acceptance of computational and experimental simulation tools for design and certification of swept-wing configurations over an expanded range of icing conditions.

Swept-wing ice-accretion characterization and aerodynamics

- Experimental ice accretion simulation
  - Develop test and model design methods for icing tunnels.
- Computational ice accretion simulation
  - Provide database of swept-wing ice accretion.
- Experimental aerodynamic simulation
  - Determine level of geometric fidelity required for accurate aerodynamics.
- Computational aerodynamic simulation
  - Provide database of iced-swept-wing aerodynamics.

# Introduction

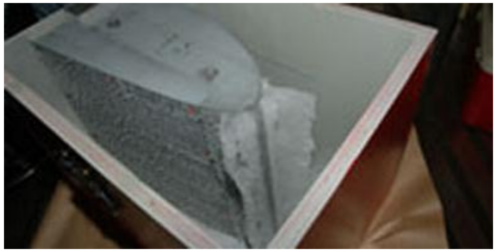


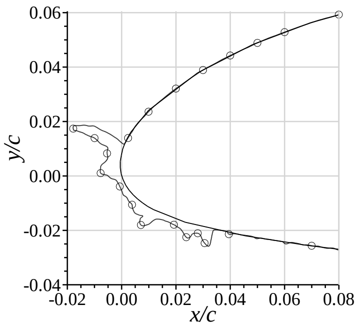
- The AEST goal for "achieving acceptance" of simulation tools for icing design and certification is based upon past experience with current simulation tools.
- Past research has focused on airfoil and straight-wing icing and aerodynamics.
- This large body of work has led to icing simulation tools such as NASA's LEWICE code and the Icing Research Tunnel that have a defined and accepted performance capability.
- Iced-aerodynamics research has led to an understanding of ice-accretion geometry fidelity and scaling requirements for airfoils.
- The fundamental differences in swept-wing ice accretion geometry and flowfield require further investigation.
- The Swept-Wing Ice Accretion Characterization and Aerodynamics research effort is a first step in extending the capabilities of computational and experimental simulation tools for ice accretion and aerodynamics to swept-wing geometries including the freezing drizzle and freezing rain environment.

# Background

3D Aerodynamic Icing Simulation

- A major part of this research effort is modeled after a successful international collaboration initiated under the first Aviation Safety Program.
- The NASA/ONERA/Illinois Icing Aerodynamics Simulation Program investigated aerodynamic effects and ice accretion simulation for 2D airfoils.
  - Ice shapes were classified according to their effect on the flowfield.
  - A benchmark database of aerodynamic effects was measured for high-fidelity ice castings on a full-scale model at near-flight Reynolds number.
  - Methods were developed for designing lower-fidelity ice shapes for a subscale model at lower Reynolds number.

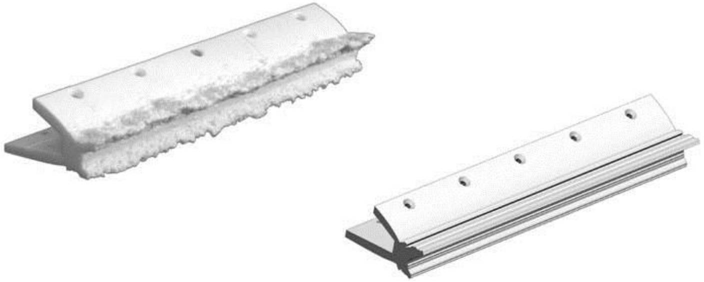



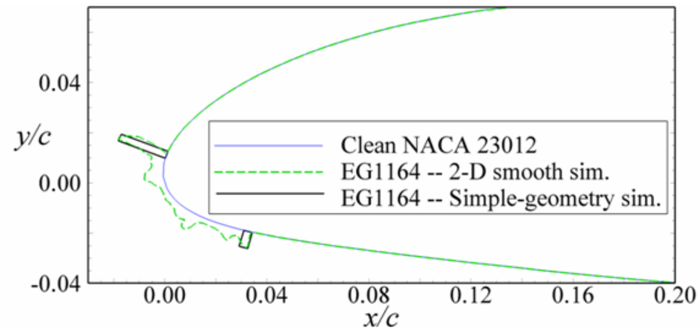


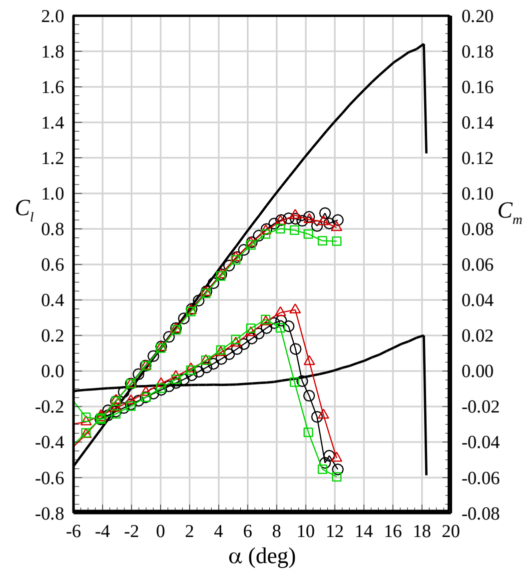
# Background

3D Aerodynamic Icing Simulation

- NASA/ONERA/Illinois Icing Aerodynamics Simulation Program Accomplishments:
  – Provided guidance as to the level of geometric fidelity required for accurate iced-airfoil aerodynamic behavior.
  – The accuracy to which the full-scale iced-airfoil aerodynamics (lift and drag) can be simulated on a subscale model at low-Reynolds number was quantified.
  – Subscale model iced-airfoil aerodynamic simulation methods validated to a known degree of uncertainty.
- This work has led to a more complete understanding of ice contamination aerodynamic effects on airfoils.
- This is an important building block, but a fundamental question remains as to how relevant 2D data are to 3D swept-wing geometries.





# Some Swept-Wing Aerodynamics Testing



- Bragg et al. (c 1990) low AR straight and swept wing with simulated ice,
  - Pressure, balance, flow viz, LDV data, low Re in Illinois tunnel
- NASA Langley/Lewis Iced Scaled Jet Transport Program (c 1996)
  - 1/8-scale twin jet at low Re
  - Balance, pressures, flow viz
- Papadakis et al. Swept Wing Icing Research (c 2003)
  - GLC 305: IRT icing and WSU aero testing at low Re
  - Balance pressures, flow viz, many simulated ice shapes
- NASA TIP in Ames 40 by 80 and WSU tunnel
- NASA Business jet icing scaling testing (c 2005)
  - Full-scale, 1/12-scale, and 5/12-scale semispan wing
  - Langley Full-Scale and Illinois tunnel, Re= 0.15 to 4.2x10$^6$

# Summary of Swept-Wing Icing



- There are no experimental aero-performance and flowfield data on the effect of ice on swept-wing aerodynamics at high-Reynolds number in the public domain.
- There are no full-scale, high-Reynolds number research quality ice accretion data on complex 3D geometries in the public domain.
- There are some good low-Reynolds number aerodynamic data by Papadakis, Ratvasky, Lee, Bragg, and others.
- We have a basic understanding of swept-wing ice accretion from IRT experiments, but mostly at small scale.

# Current Situation & Motivation



- Simulation tools such as NASA LEWICE 3D and other icing codes are being developed for swept-wing ice accretions but the validation data are limited, particularly for large-scale wing geometries.
- An understanding of icing effects on swept-wing aerodynamics is critical to evaluating the accuracy to which ice accretions must be predicted by computational tools or simulated in aerodynamic testing.
- An understanding of scale effects including Reynolds and Mach number is needed to develop/validate lower cost aerodynamic test techniques for iced swept wings.
- Aerodynamic data are needed for validation of computational flow simulation (CFD) codes for iced-wing configurations.

# Research Plan



## Overall Goal

- Improve the fidelity of experimental and computational simulation methods for swept-wing ice accretion formation and resulting aerodynamic effect.

## Objectives

- Generate a database of 3D ice-accretion geometry for icing-code development and validation and for aerodynamic testing.
- Develop a systematic understanding of the aerodynamic effect of icing on swept-wings including: Reynolds and Mach number effects, important flowfield physics and fundamental differences from 2D.
- Determine the level of geometric fidelity required for accurate aerodynamic simulation of swept-wing icing effects.

# Research Plan



## Research Approach Overview

- Design and select wing geometric parameters including airfoil section to establish a baseline swept-wing model.
- Classify ice accretion on swept wings based upon governing flowfield physics.
- Conduct icing-tunnel testing over a range of conditions to develop a database of swept-wing ice accretions.
- Adapt commercial 3D laser scanning and other methods to measure highly 3D ice accretion.
- Conduct high-Reynolds number aerodynamic testing
  - Develop artificial ice shapes from icing-tunnel testing.
  - Varying the geometric fidelity of the artificial ice shapes.
  - Measure aerodynamic effects over a large range of Reynolds and Mach number.
  - Document important flowfield features where possible.

# Research Plan



## Research Approach Overview

- Develop low-cost, low-Reynolds number test capability
  - Validate against the high-Reynolds number data.
  - Investigate ice-shape parametric effects such as size, location, surface roughness, etc.
  - Identify critical cases.
- Conduct a second high-Reynolds number aerodynamic using critical configurations.
- Update the ice classifications based upon these results.

# Research Plan



## Research Products

- Database of swept-wing ice accretion.
- Database of high-Reynolds number aerodynamic data for swept-wing ice accretion.
- An understanding of the geometric fidelity required for accurate aerodynamic simulation of swept-wing ice accretion.
- A validated low-cost, low-Reynolds number test capability for evaluation of performance characteristics and aerodynamics of iced-swept-wing geometries.
- Improved methods for quantifying ice accretion geometry and developing high-fidelity artificial ice shapes.
- Improved computational and experimental simulation tools for swept wings.

# Research Roadmap



**Program organized into six phases:**

- Phase I:  Ice-Shape Classification
- Phase II:  Ice-Accretion and Aerodynamic Measurement Methods Development
- Phase III:  Ice-Accretion Testing
- Phase IV: High-Reynolds Number Aerodynamic Testing
- Phase V:  Low-Reynolds Number Aerodynamic Testing
- Phase VI:  High-Reynolds Number Validation Testing

# Research Roadmap



- **Phase I: Ice-Shape Classification**
  - Develop simulation requirements.
  - Classify ice shapes according to unique iced-wing flowfield features.
- **Phase II: Ice-Accretion and Aerodynamic Measurement Methods Development**
  - Design and select a baseline swept-wing geometry (airfoil, sweep angle, taper ratio, aspect ratio, span, high-lift devices, control surfaces, etc.) representative of modern transport wing.
  - Adapt and validate commercial 3D laser scanning methods for measuring ice accretion geometry.
  - Define fabrication methods for ice-shape simulations using 3D laser scan data.

# Research Roadmap



- **Phase III: Ice-Accretion Testing**
  - Design models and experiments for ice accretion testing. Evaluate icing simulation capability for full-scale swept wing sections in the NASA IRT.
  - Design and build NASA IRT models.
  - Design NASA IRT test matrix.
  - Conduct ice-accretion testing in NASA IRT
- **Phase IV: High-Reynolds Number Aerodynamic Testing**
  - Design and build high-Reynolds number aerodynamic model for ONERA F1 tunnel.
  - Select ice accretions to be simulated based upon classifications developed in Phase I.
  - Design and build artificial ice shapes with varying geometric fidelity.
  - Conduct aerodynamic testing.

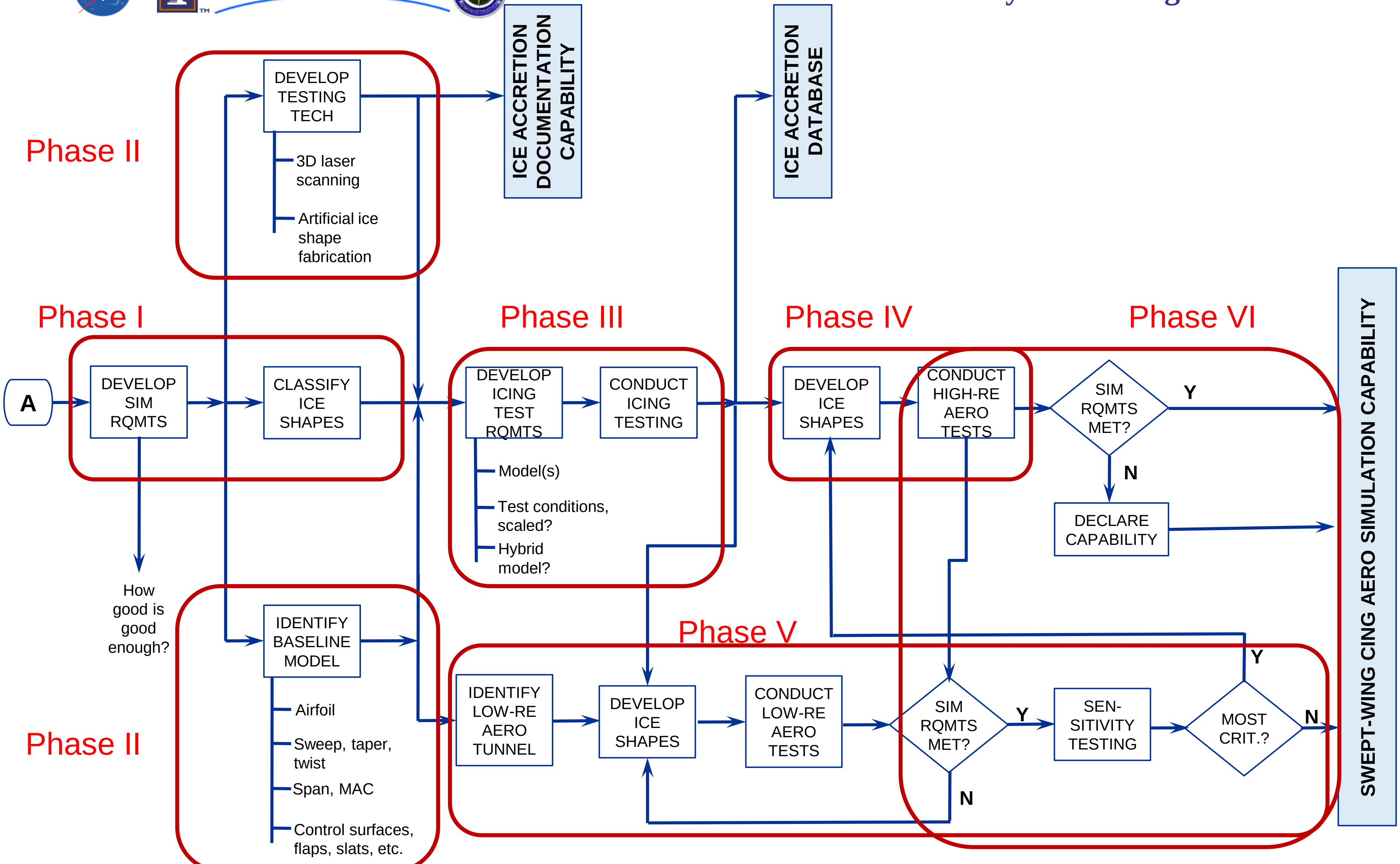
# Research Roadmap



- **Phase V: Low-Reynolds Number Aerodynamic Testing**
  - Design and build low-Reynolds number aerodynamic model.
  - Design and build artificial ice shapes based on high-Re test.
  - Conduct low-Reynolds number test campaign to baseline model and ice-shape aerodynamic effects.
  - Quantify differences in aerodynamic coefficients between low- and high-Reynolds number testing.
  - Conduct ice-shape sensitivity test to explore range of ice shape aero effects and identify critical configurations.
- **Phase VI: High-Reynolds Number Validation Testing**
  - Conduct a second high-Reynolds number ONERA F1 test campaign.
  - Confirm aerodynamic penalties associated with most sensitive ice shape parameters derived from low-Reynolds number testing.
  - Update ice-shape classifications and quantify aerodynamic uncertainty associated with varying levels of geometric fidelity, including Re and M effects.

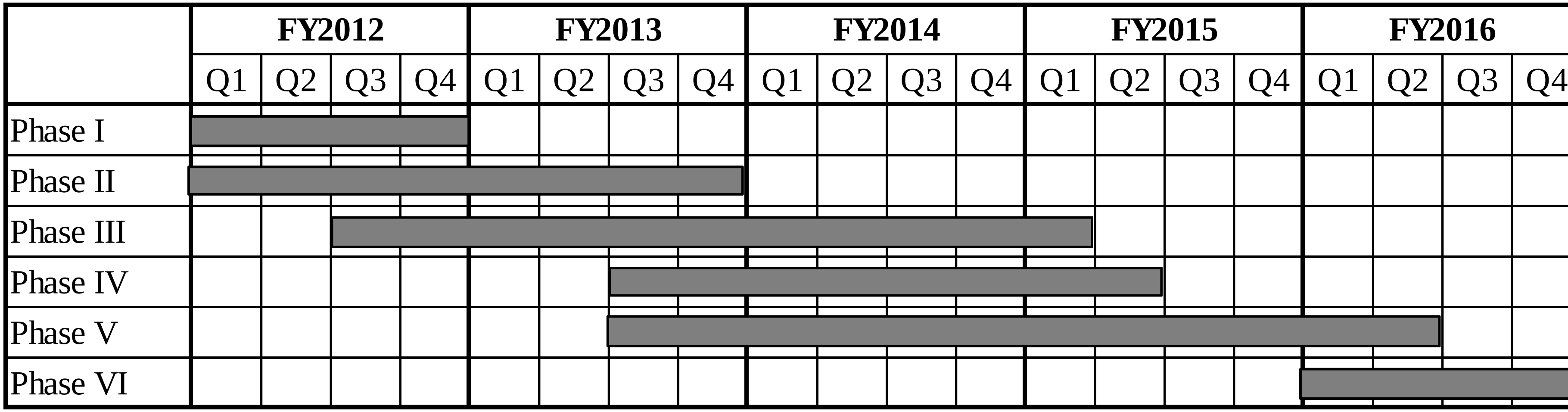
# Swept-Wing Icing Research Roadmap

3D Aerodynamic Icing Simulation



# Schedule

3D Aerodynamic Icing Simulation




- Phase I: Ice-Shape Classification
- Phase II: Ice-Accretion and Aerodynamic Measurement Methods Development
- Phase III: Ice-Accretion Testing
- Phase IV: High-Reynolds Number Aerodynamic Testing
- Phase V: Low-Reynolds Number Aerodynamic Testing
- Phase VI: High-Reynolds Number Validation Testing

# Proposed Research Funding



## Total Estimated Project Cost = $7.0M (USD)

- Major budget drivers:
  - People
  - Wind-tunnel models and artificial ice shapes
  - Total wind tunnel occupancy time (assume NASA IRT, ONERA F1 and 7x10 size low-Re tunnel)
  - Other costs include travel and equipment such as 3D laser scanner

## Estimated Budget Allocations

- NASA = $2.8M
- FAA = $2.1M
- ONERA = $2.1M

# Current Status



## Collaboration

- NASA and FAA have mutual commitment to carrying out this research.
- FAA currently funding University of Illinois to support this research.
- Proposed work presented to ONERA colleagues, currently awaiting their response.
- Proposed work presented to industry colleagues for comment and in-kind support.
- Supporting NRA topic has been written, awaiting release of solicitation.

## Phase I: Ice-Shape Classification

- Initial literature review and draft classifications have been developed.
- Expect initial document release for review and comment by end of FY2011.

## Phase II: Ice Accretion and Aerodynamic Measurement Methods

- Currently evaluating commercial 3D scanning technology for use in NASA IRT.
- More details in the following presentation by Sam Lee.

# Summary



- A significant effort within the Airframe Icing Technical Challenge of the AEST project is dedicated to improving computational and experimental simulation methods for swept-wing icing.
- Multiple ice accretion and aerodynamic experiments are planned to develop the experimental simulation capability and provide validation databases for the development of computational simulation capabilities.
- This is a collaborative effort among NASA, FAA, ONERA, Univ. of Illinois and industry partners.